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MINOS Experiment

NuFact'00 Workshop

May 22-26, 2000, Monterey, California, USA

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California Institute of Technology

- Introduction
- Neutrino Beam
- MINOS Detector
- Physics Reach

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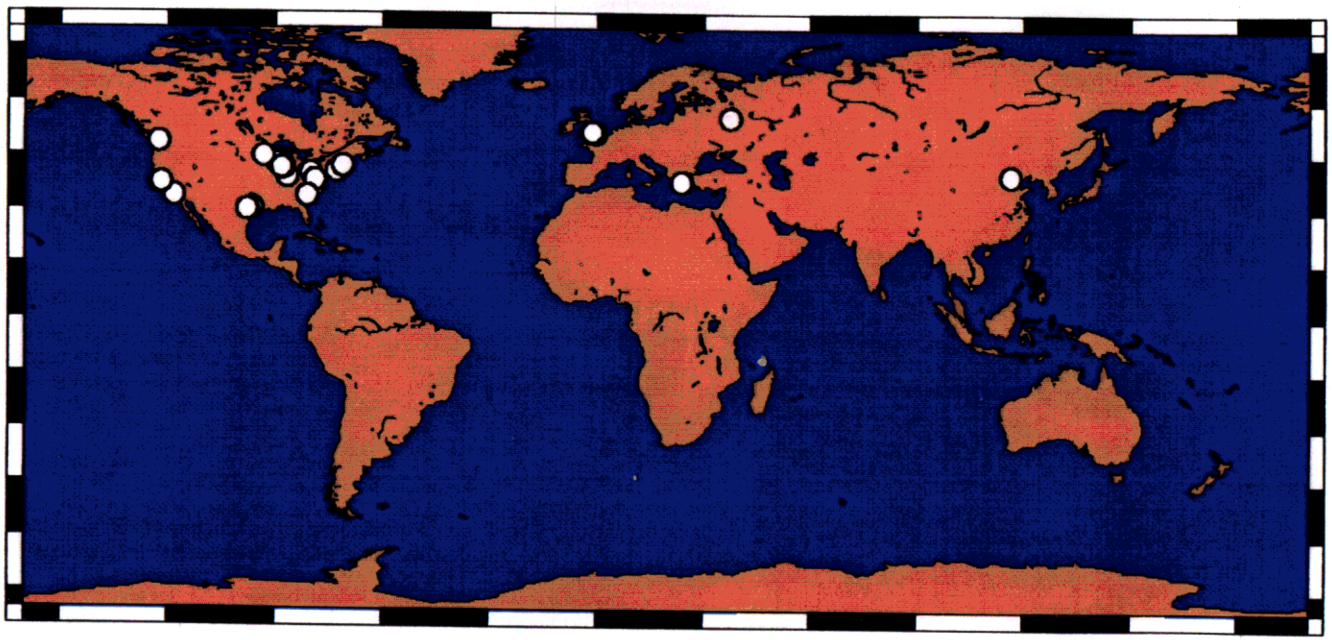
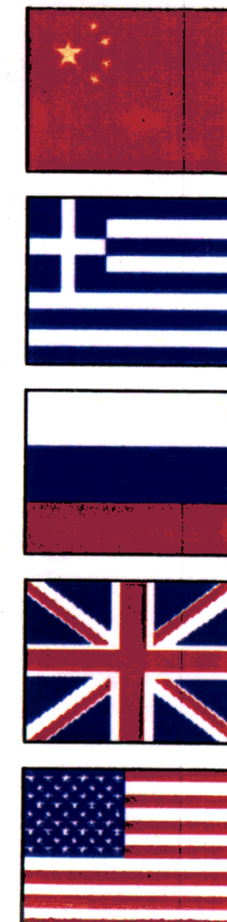
The MINOS Collaboration





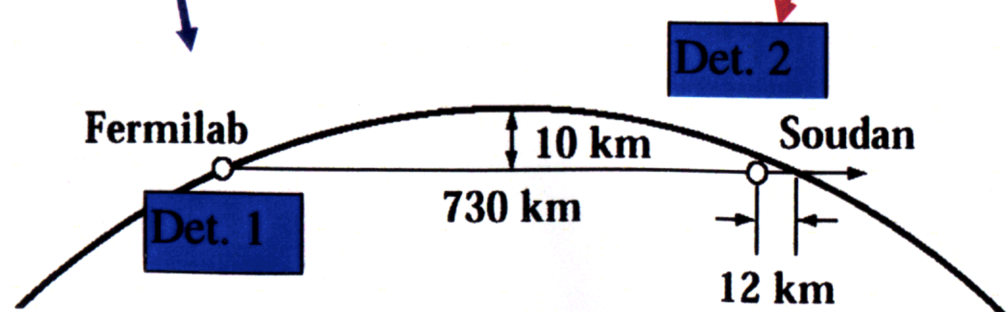
Over 250 Physicists and Engineers

IHEP-Beijing · Athens · Dubna · ITEP-Moscow · Lebedev · Protvino · Oxford · Rutherford · Sussex · University College London · Argonne · Brookhaven · Caltech · Chicago · Elmhurst · Fermilab · James Madison · Harvard · Indiana · Livermore · Minnesota · Northwestern · Pittsburgh · South Carolina · Stanford · Texas-Austin · Texas A&M · Tufts · Western Washington · Wisconsin

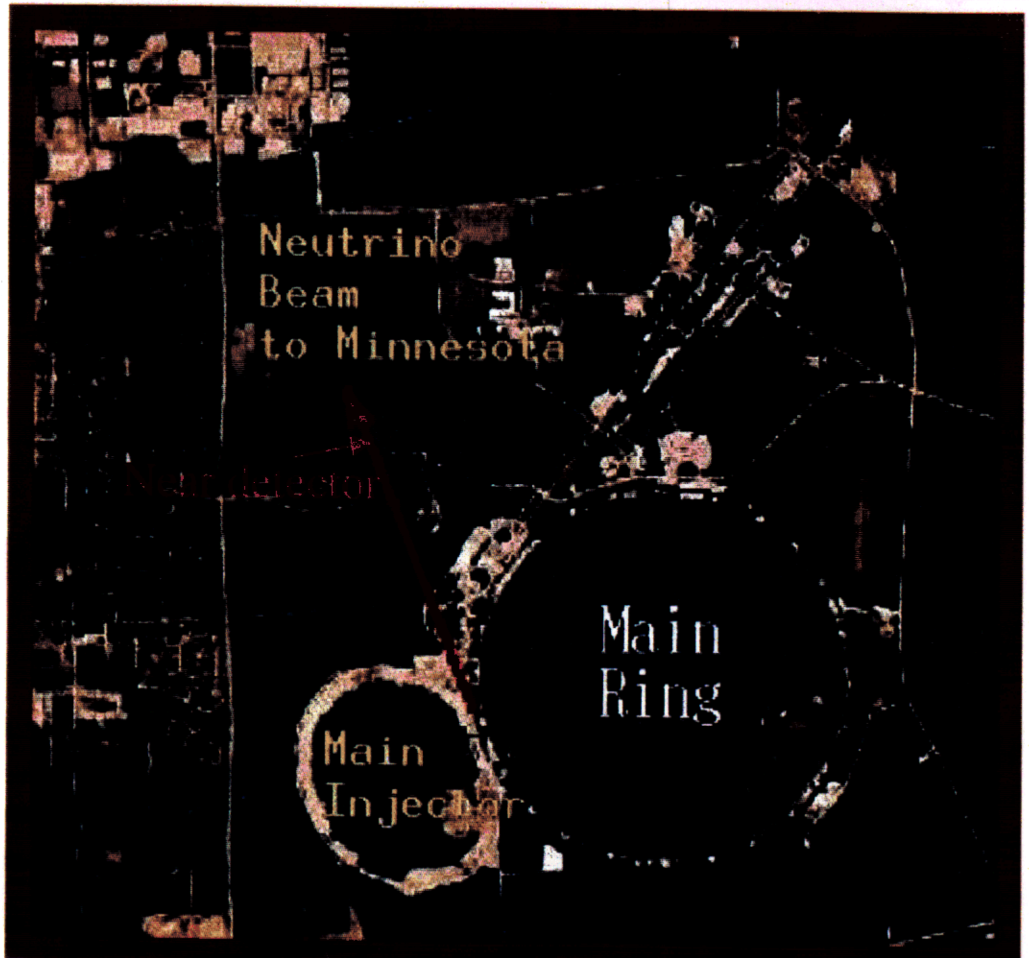
MINOS Experiment

Near Detector: 980 tons

Far Detector: 5400 tons



Neutrinos at the Main Injector (NuMI)



- 120 GeV protons
- 1.9 second cycle time
- 4×10^{13} protons/pulse
- Single turn extraction (10μs; possible upgrade to 1 ms resonant extraction)
- 4×10^{20} protons/year
- 700 m x 2 m diameter decay pipe for neutrino beam.
- 200 m rock absorber.
- Near detector complex.

Producing a Neutrino Beam

120 GeV protons hit target (10^{20}/Protons per year!)

π^+ ("pions") produced at wide range of angles

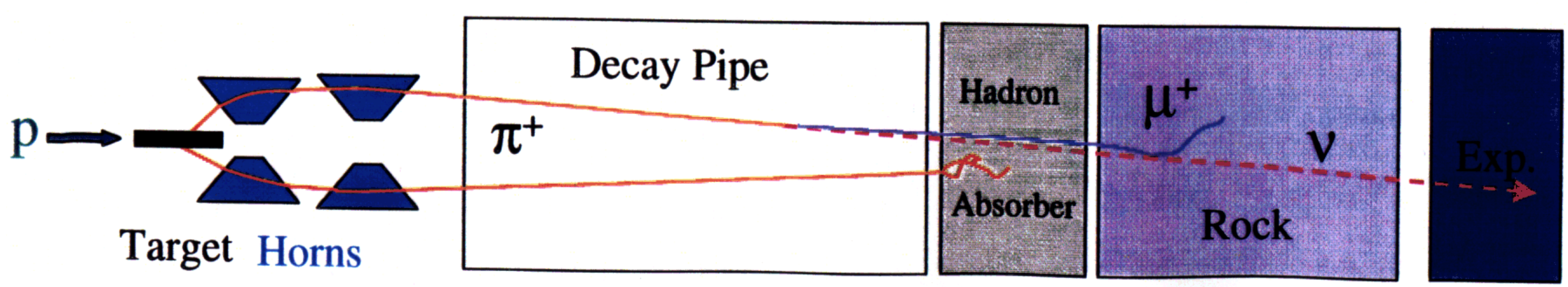
Magnetic horns to focus π^+

π^+ decay to $\mu^+\nu$ in long evacuated pipe

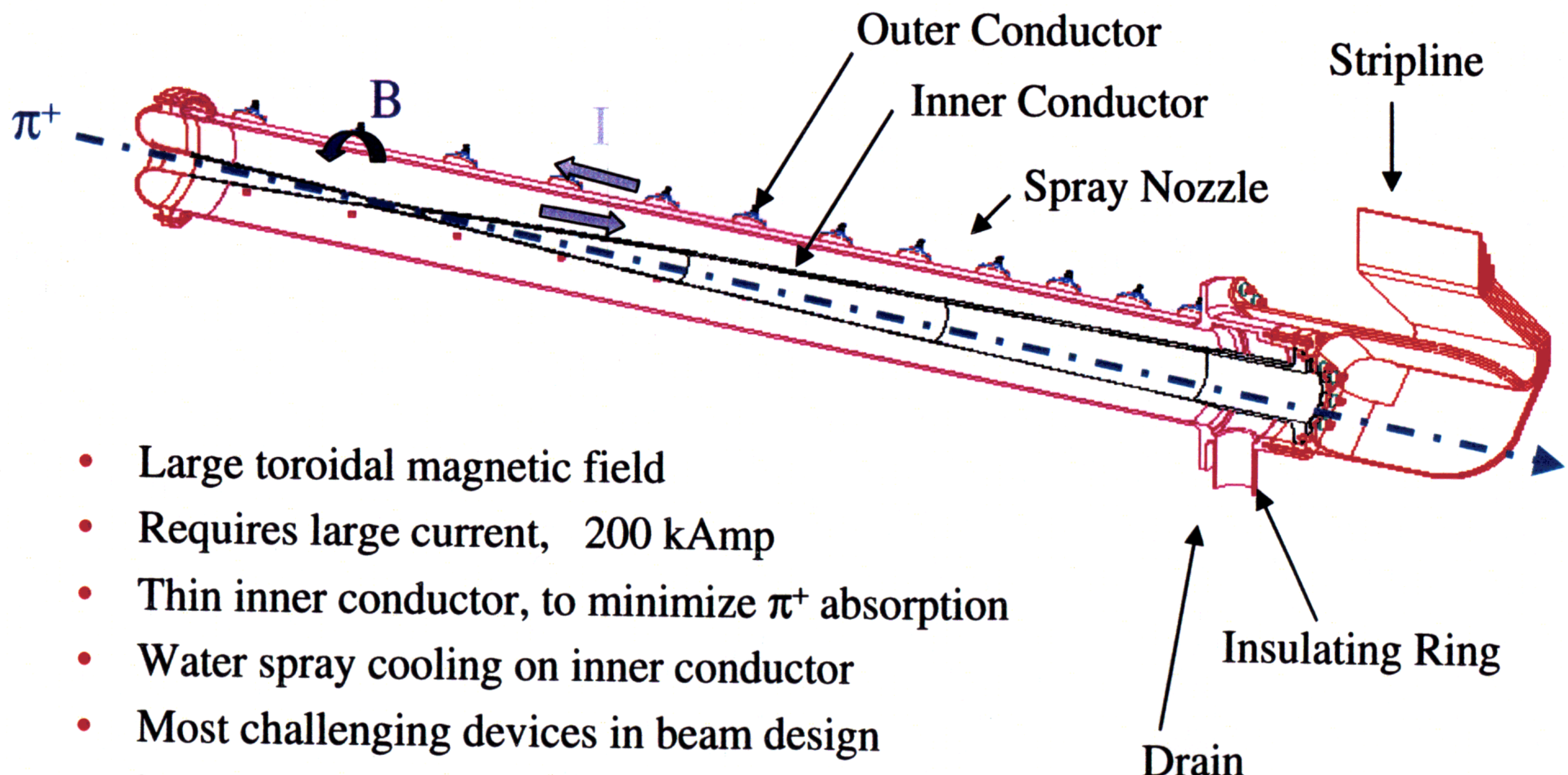
Left-over hadrons shower in hadron absorber

Rock shield ranges out μ^+

ν beam travels through earth to experiment



Magnetic Horns



- Large toroidal magnetic field
- Requires large current, 200 kAmp
- Thin inner conductor, to minimize π^+ absorption
- Water spray cooling on inner conductor
- Most challenging devices in beam design
- Prototype test 1999-2000 to check design

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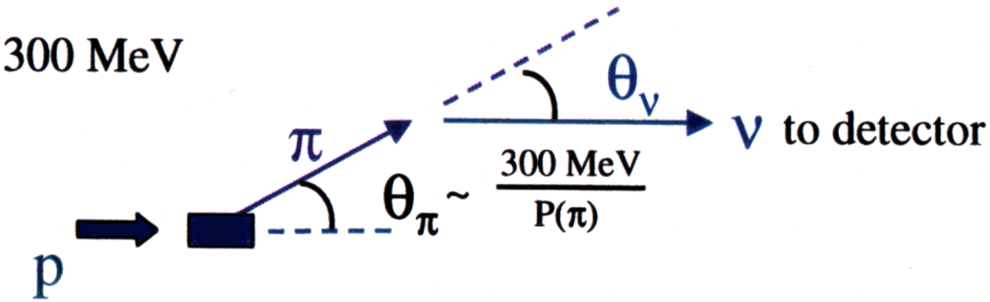
π^+ Production, Focusing, Decay

$P_t(\pi) \sim 300$ MeV

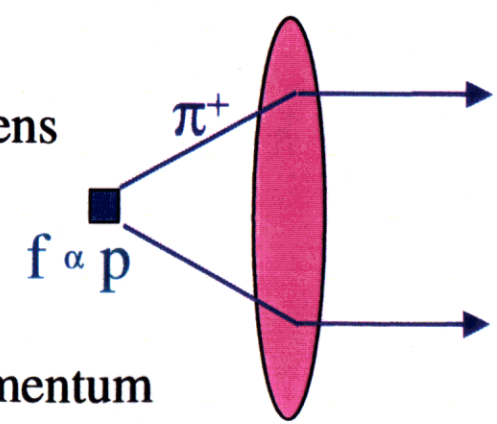


$$E_\nu \sim \frac{0.43\, E_\pi}{1 + \gamma_\pi^2\theta_\nu^2}$$

$$\text{Flux} \sim \frac{\gamma_\pi^2}{(1 + \gamma_\pi^2\theta_\nu^2)^2}$$

- Without focusing, flux to detector is only ~1/25 of flux in pion direction

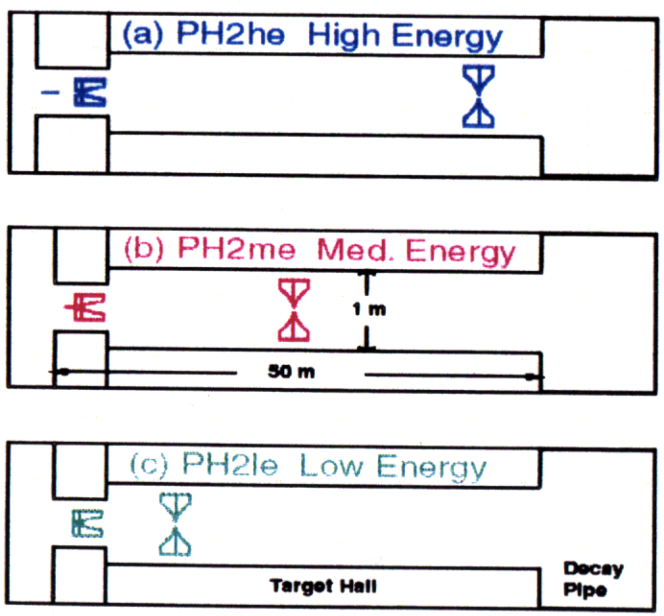
- With a parabolic shaped horn inner conductor,
  B dL (i.e. p_t kick) is linear with radius -> lens

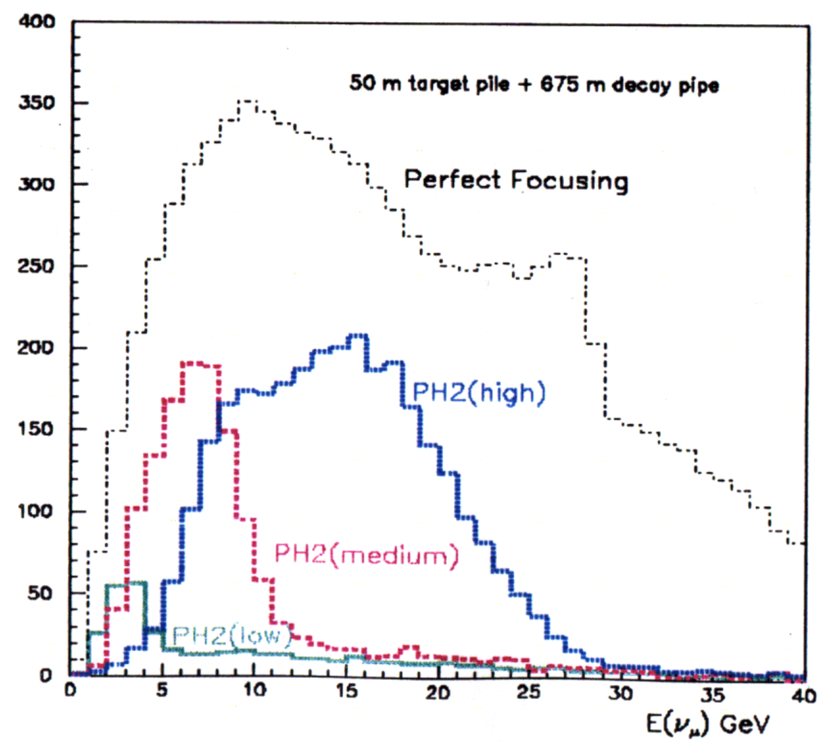


- The focal length is proportional to p:
  choice of target to horn distance selects momentum

- π focused parallel by horn 1 go through hole in horn 2;
  somewhat under or overfocused π are focused by horn 2

PH2 Horn Configurations and Neutrino Spectra





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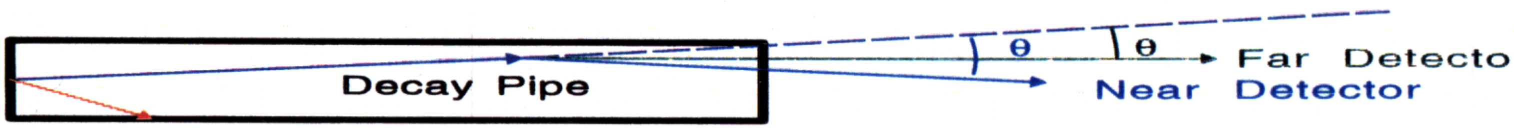
The Hadronic Hose

SOURCES OF FAR/NEAR SPECTRUM DIFFERENCES



$1/L^2$ distribution to Near Detector depends on:

* where hit decay pipe wall
* pion lifetime

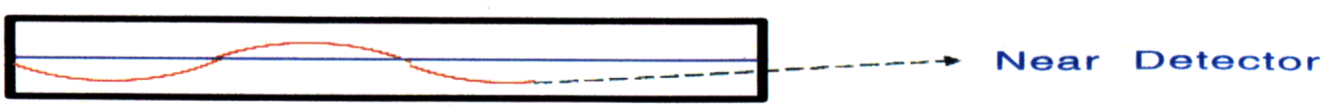
θ to Near Detector larger than θ to Far Detector hence E, Flux are different

$$E_\nu \propto \frac{1}{1+\gamma^2\theta^2} \qquad \nu \text{ Flux } \propto \frac{1}{L^2}\left(\frac{1}{1+\gamma^2\theta^2}\right)^2$$

*** *** HADRONIC HOSE CONCEPT *** ***

Continuous focusing reduces Far/Near difference

Wire in decay pipe
I= 0.5 to 1 kA



* dont let hadrons hit walls

(* but can't change pion lifetime)

Angular distribution to Far and Near now much more similar

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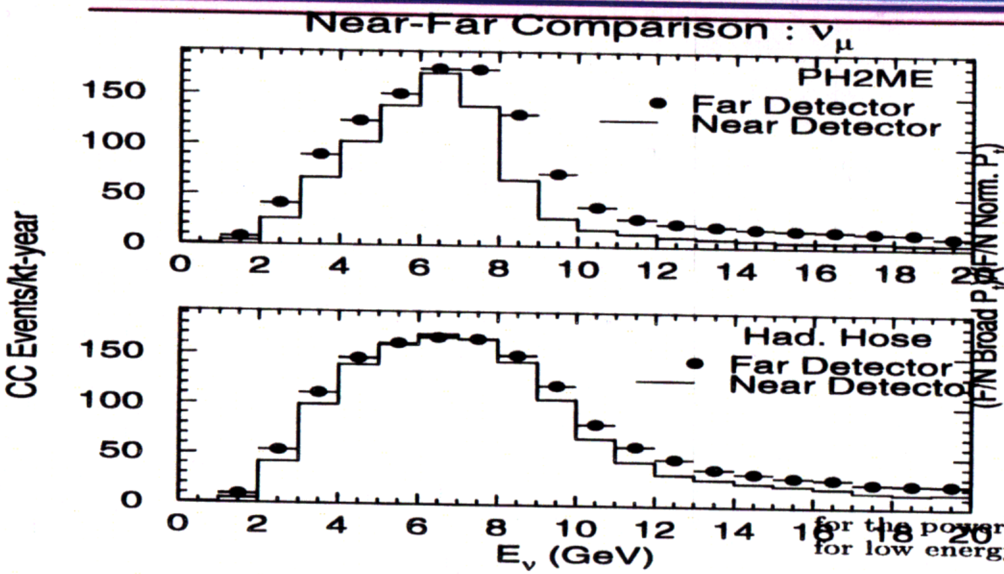
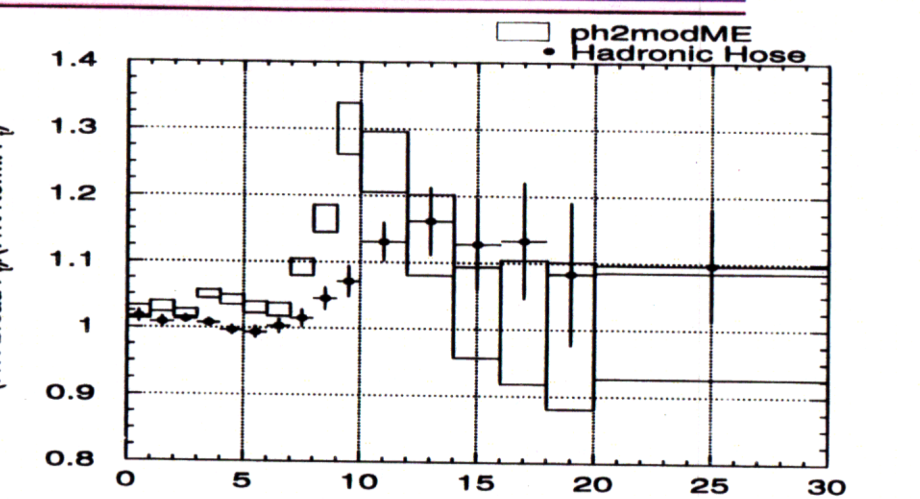
Spectra from Hadronic Hose vs Conventional Focus





for the power supply). This would be desirable to achieve the highest event r
for low energy beam.

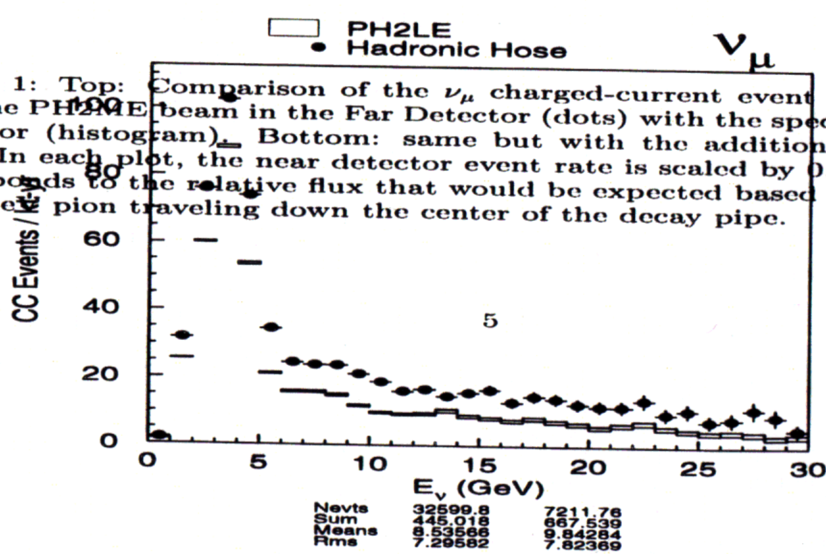


Figure 1: Top: Comparison of the ν_μ charged-current event spectrum for the baseline PH2ME beam in the Far Detector (dots) with the spectrum in the Near Detector (histogram). Bottom: same but with the addition of the Hadronic Hose. In each plot, the near detector event rate is scaled by 0.77×10^{-6}, which corresponds to the relative flux that would be expected based on the lifetime of a 10 GeV pion traveling down the center of the decay pipe.

Figure 4: Relative variation in the far/near comparison when the hadronic production p_t spectrum is varied, for the basline PH2ME design (boxes) an[illegible] Hadronic Hose (points). Box size and point error bars represent Monte [illegible] statistical errors. The impact of p_t uncertainty is a factor of three less i[illegible] Hadronic Hose case, and below 8 GeV the Hadronic Hose beamline show[illegible] no significant variation at all.

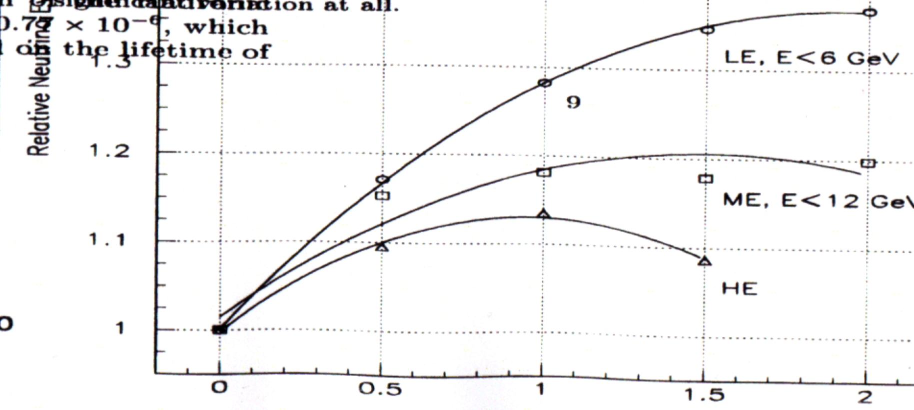


Figure 27: The low energy beam far detector ν_μ CC spectrum. The baseline low energy beam is shown by boxes and the baseline with the addition of the

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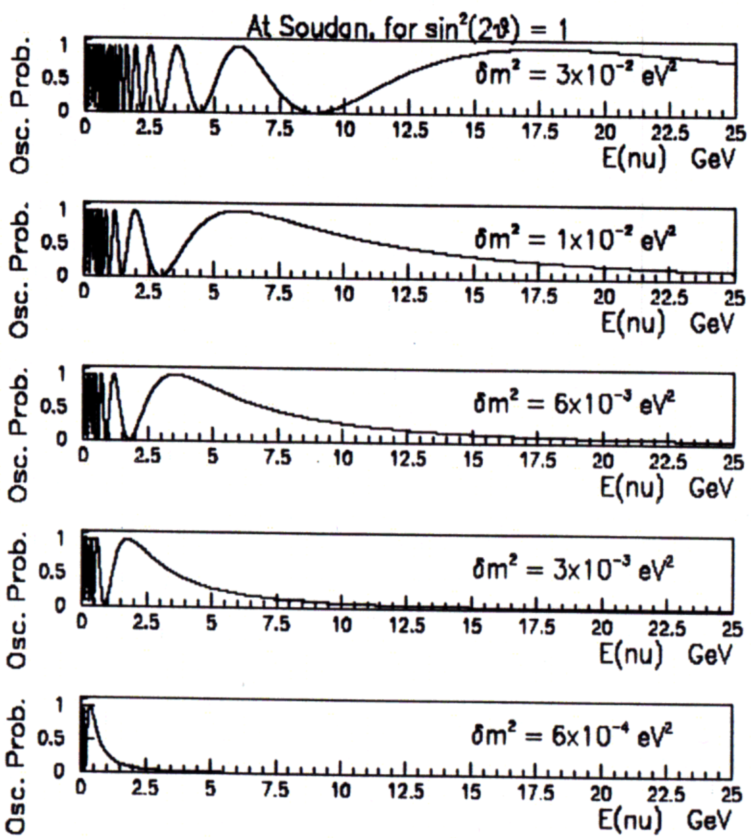
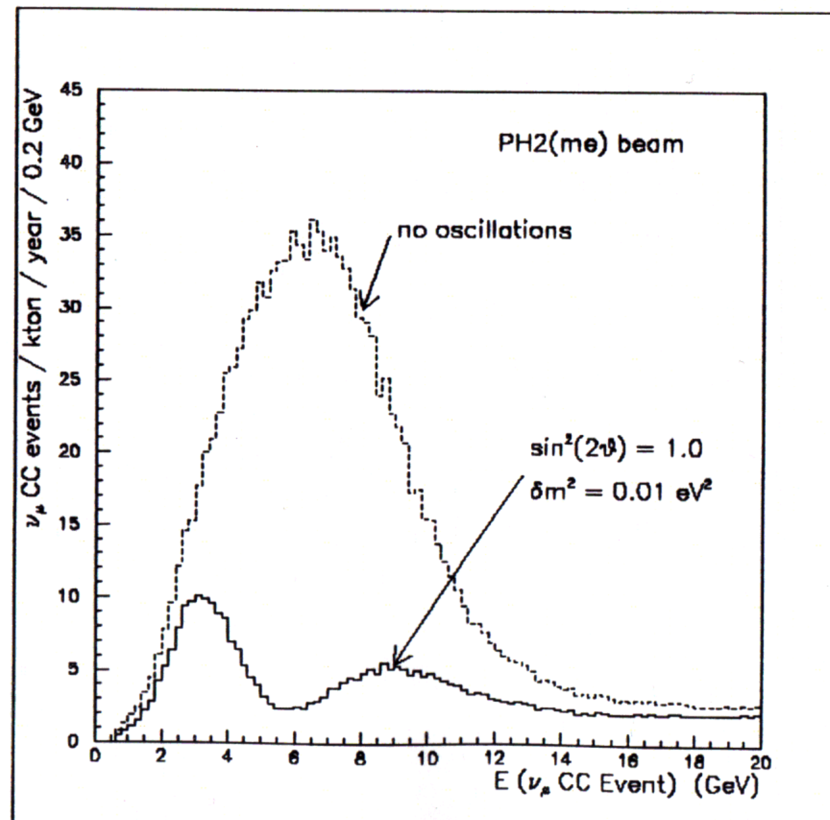
What Neutrino Beam Energy to Choose?

(Sample Osc. Prob. at Soudan spanning Kamiokande and SuperK regions)





Around highest energy oscillation node!

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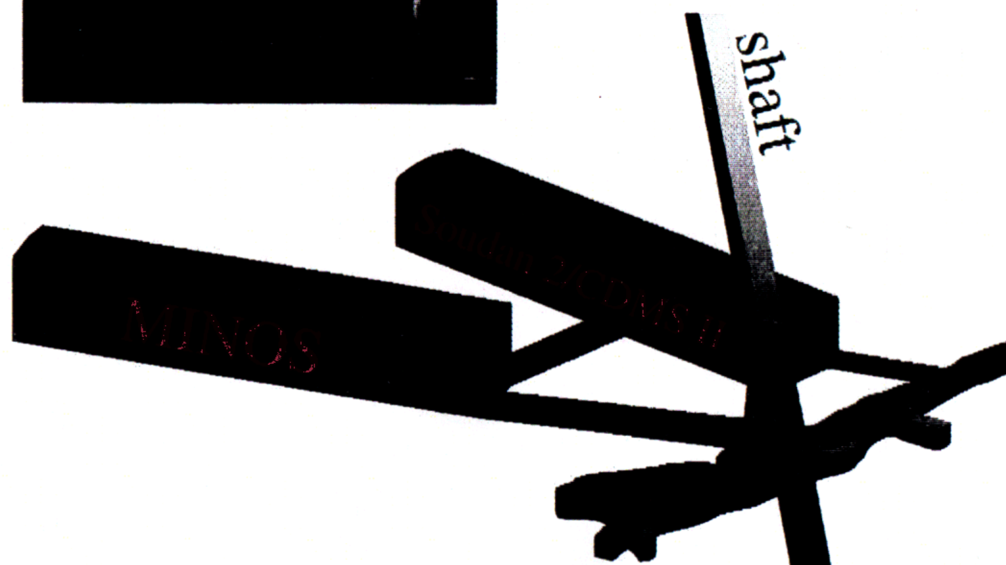
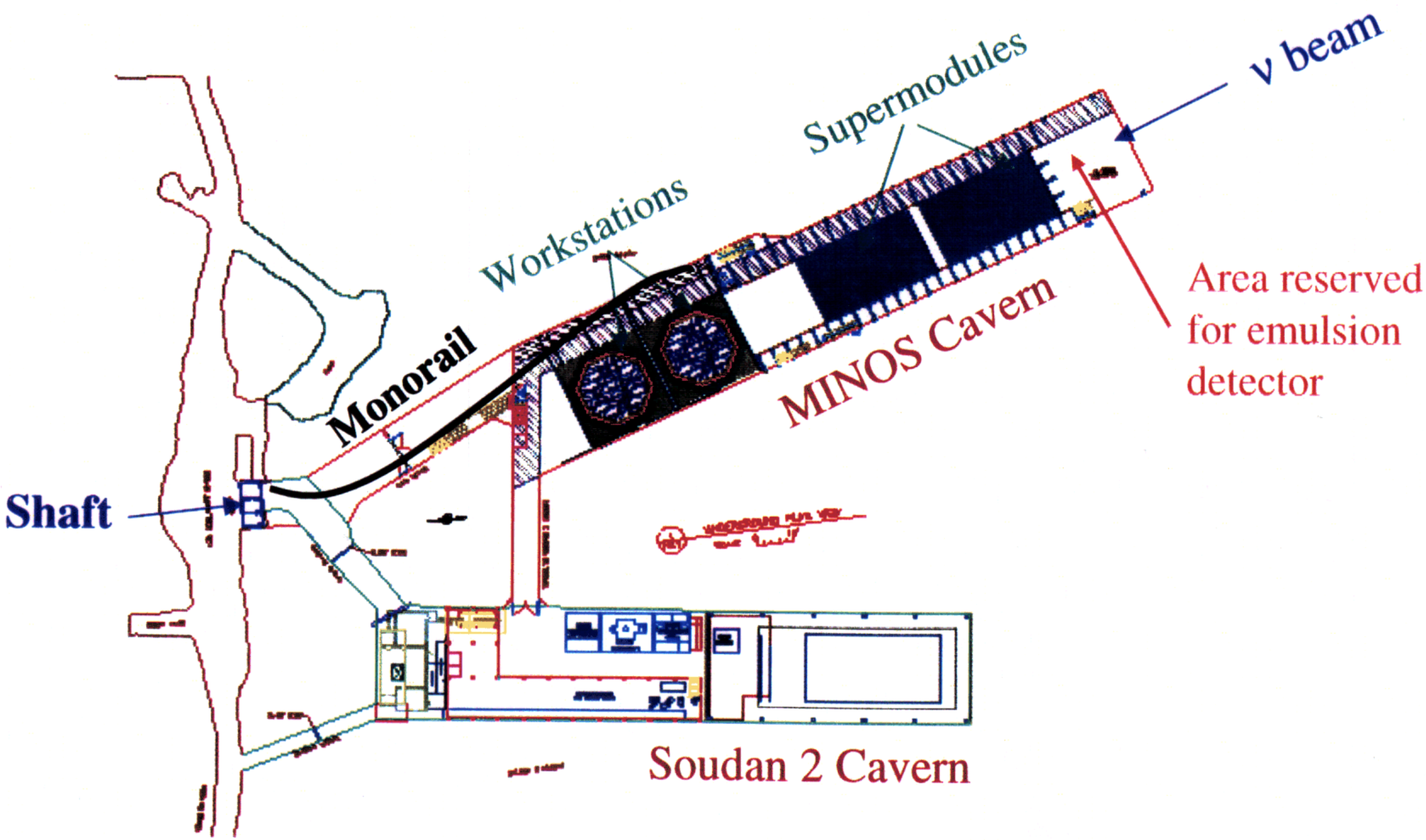
Soudan Underground Laboratory

Headframe of the Soudan Iron Mine (former) State Park and Laboratory

The Soudan shaft limits objects to a maximum size of 1m by 2m by 9m

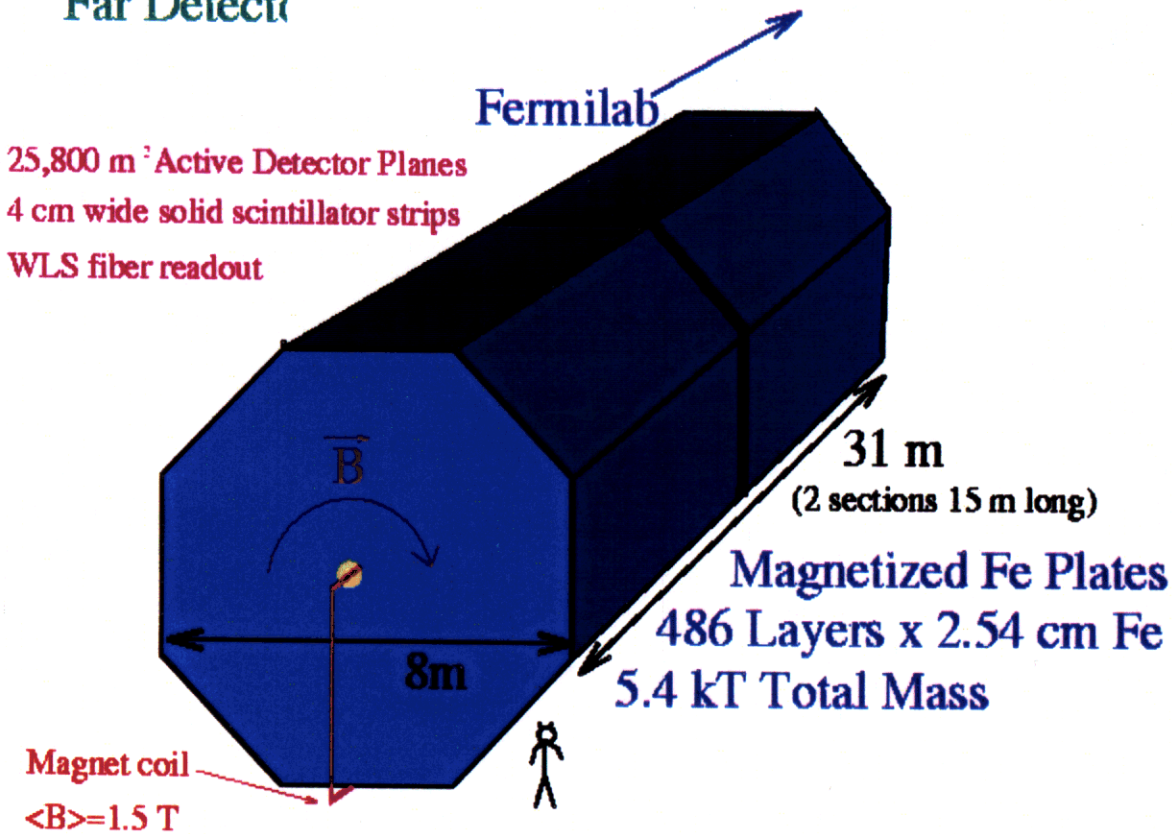


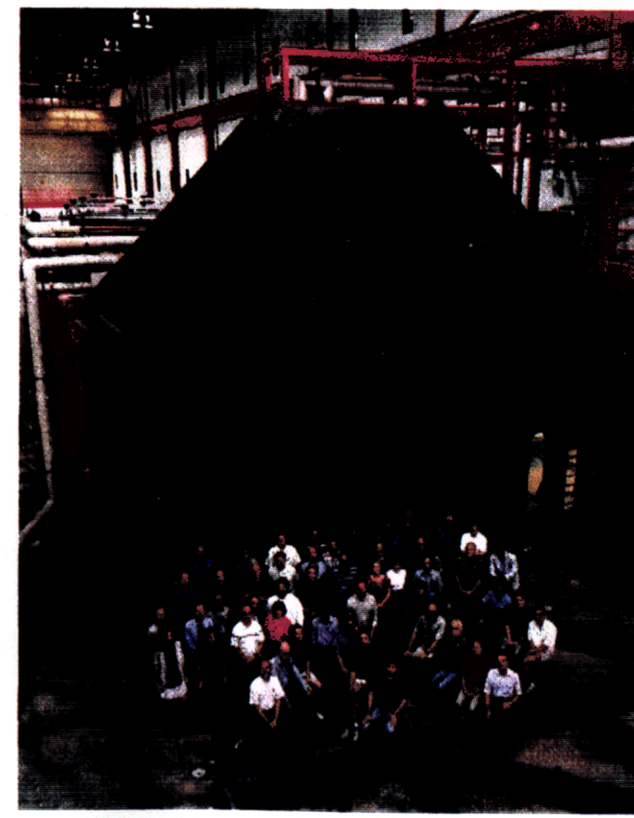
Far Detector Cavern Layout



MINOS Far Detector

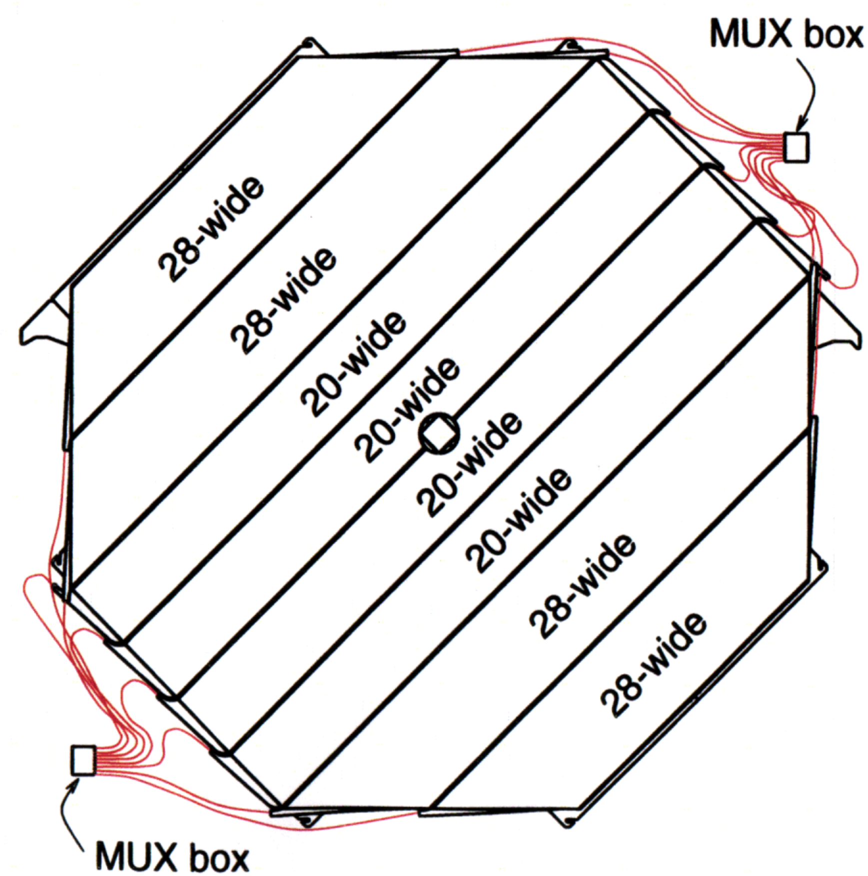
Far Detect





Far Detector Module Layout

- 8 modules cover one far detector steel plane
- Four 20-wide modules in middle (perp. ends)
- Four 28-wide modules on edges (45 deg ends)
- Two center modules have coil-hole cutout



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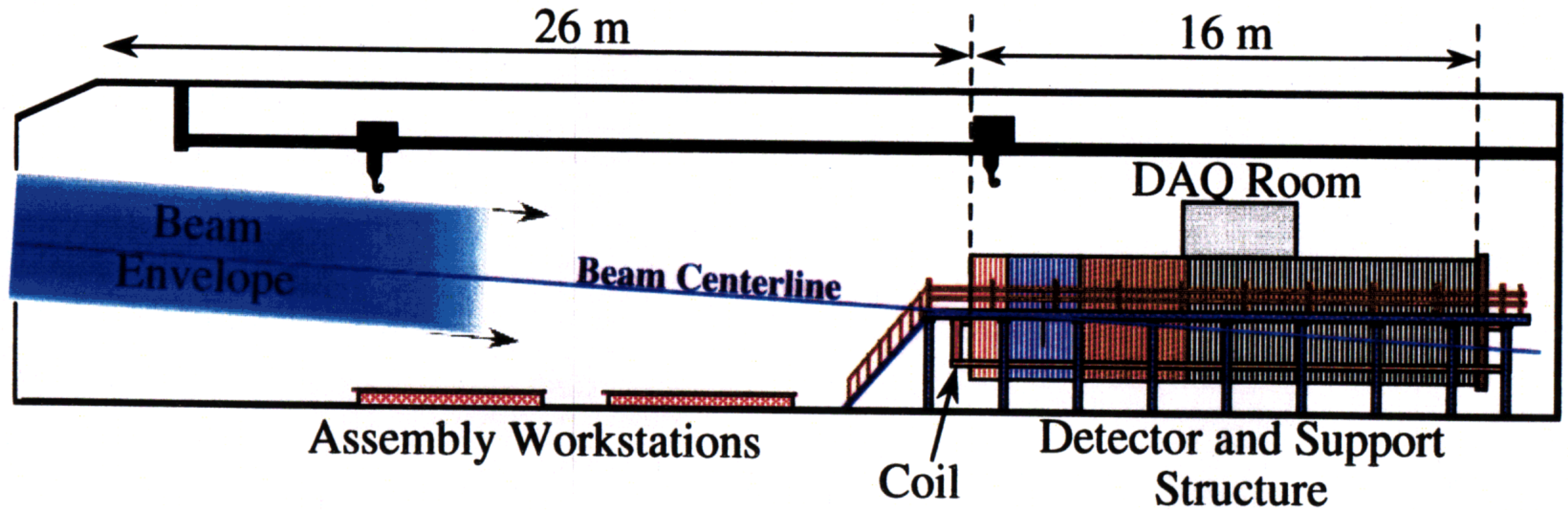
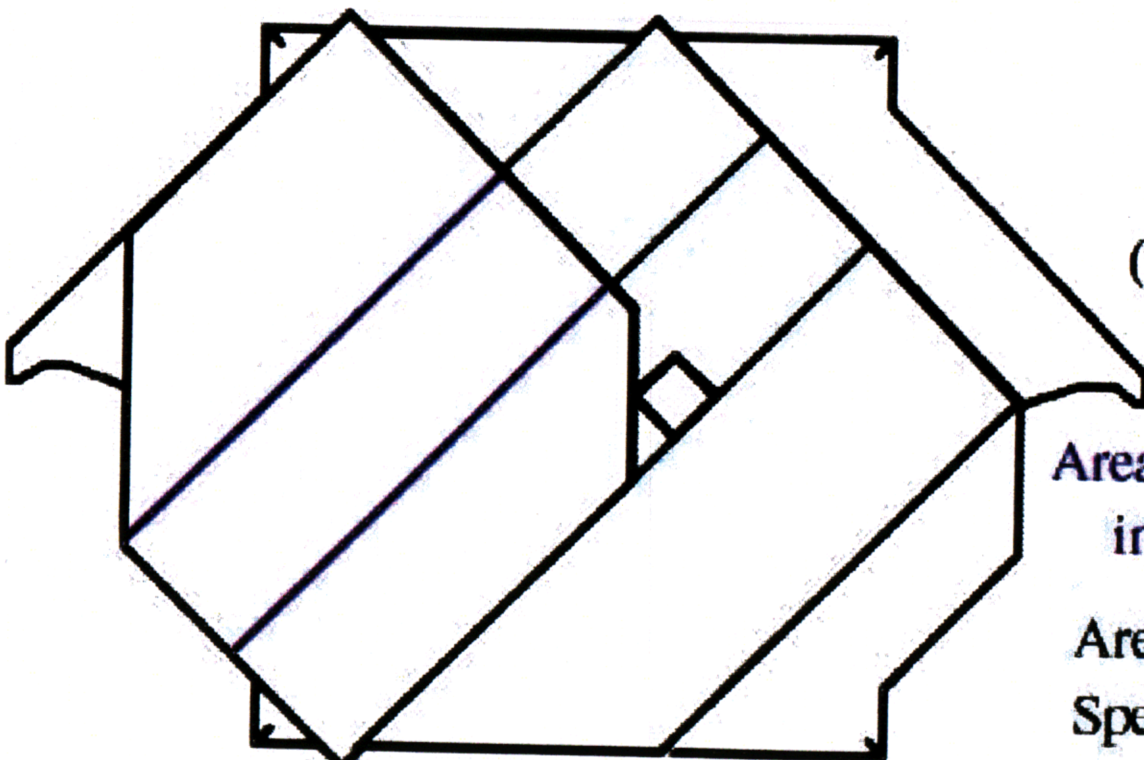
Near Detector Side View



Near Module Layout



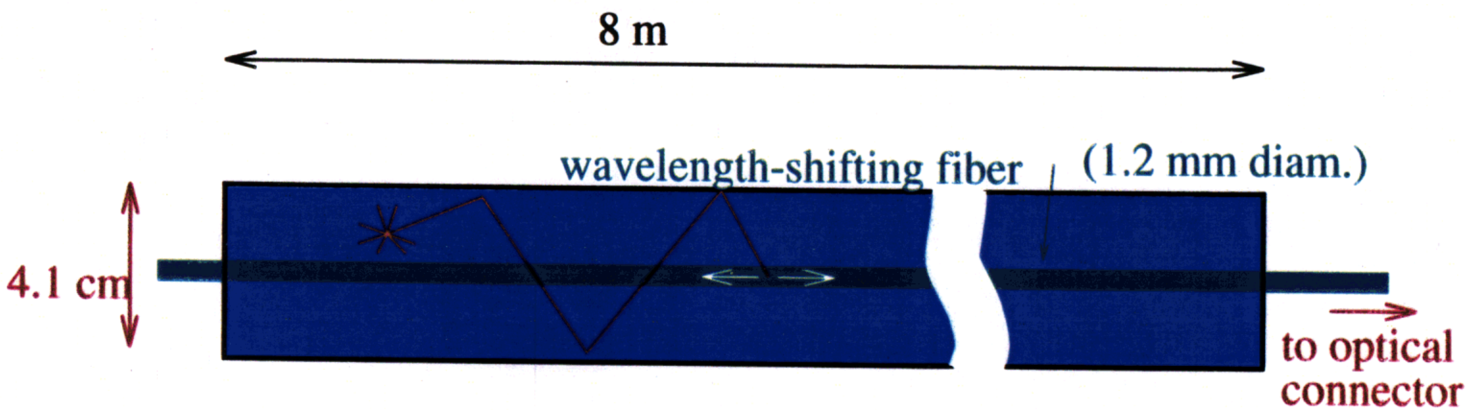
Total area of steel (without ears) = $16.2\ m^2$

Area of "partial cover" modules in Forward section ~ $6\ m^2$

Area of "full cover" modules in Spectrometer section ~ $13.2\ m^2$

Some changes under study.

Scintillator Strip WLS Fiber Readout

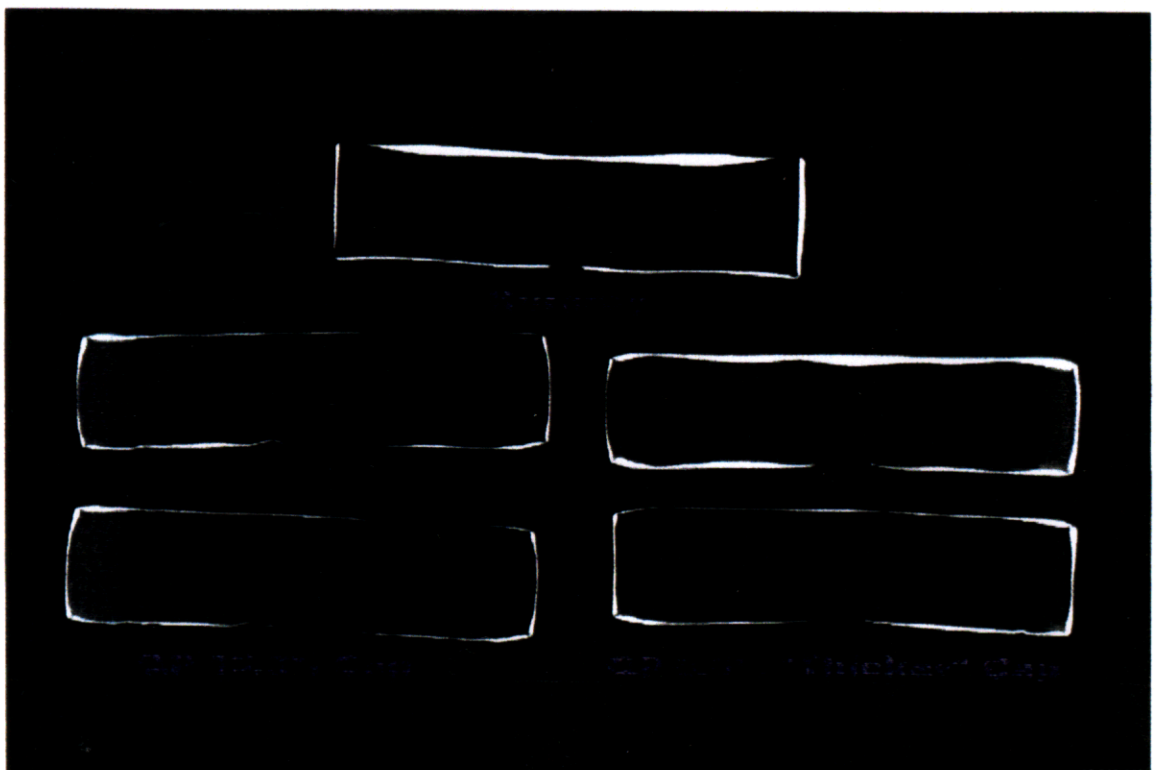


1.0 cm x 4.1 cm extruded polystyrene scintillator

- Scintillator strips are commercially extruded polystyrene
  - PPO and POPOP fluors
  - Wavelength-shifting (WLS) fiber groove
  - Co-extruded TiO_2 reflective cap
- Groups of 20 or 28 strips are assembled into "modules"

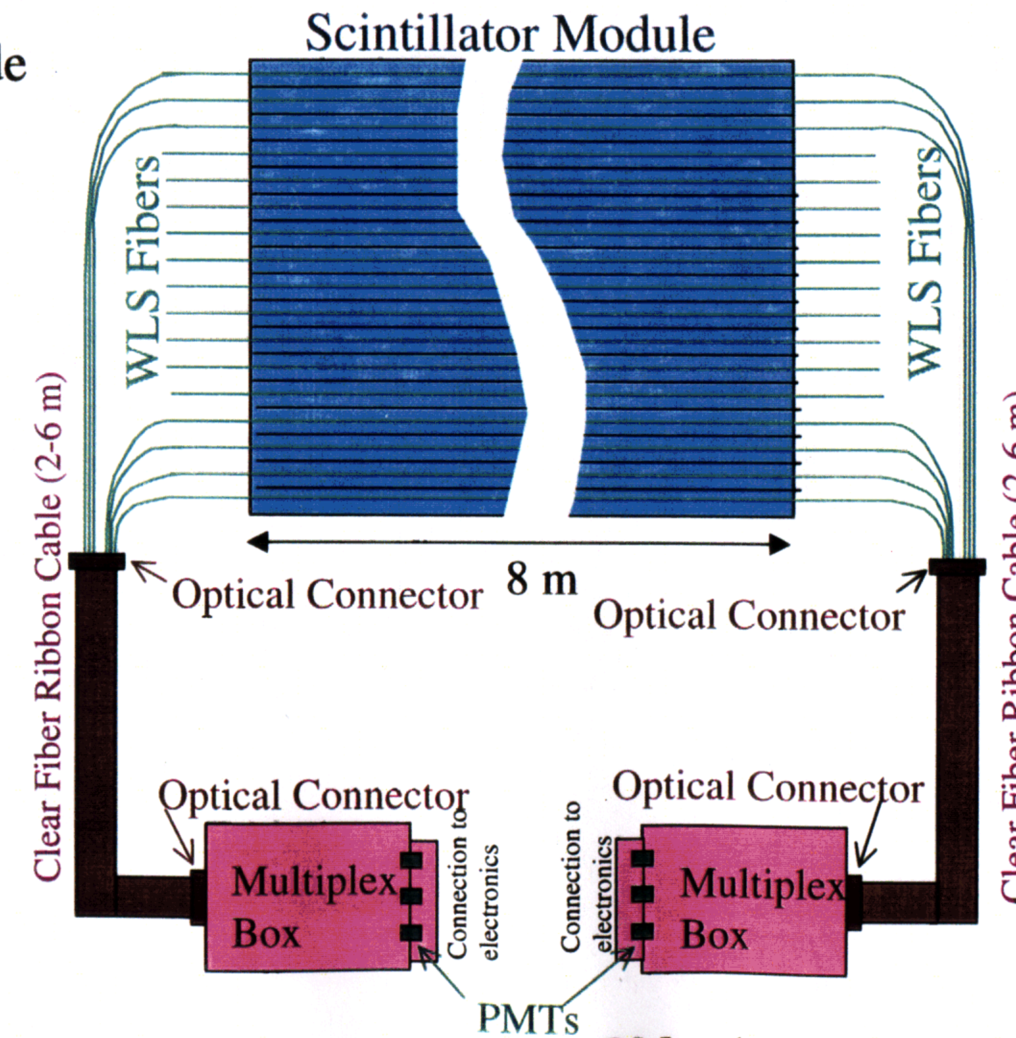
Extruded Scintillator

Cross section of co-extruded scintillator strips



Schematic View of the MINOS Scintillator System

- Extruded scintillator, 4cm wide
- Two-ended WLS fiber readout.
- Strips assembled into 20 or 28-wide modules.
- WLS fibers routed to optical connectors.
- Light routed from modules to PMTs via clear fibers.
- 8 Fibers/PMT pixel in far detector. (Fibers separated by ~1m in a single plane.
- 1 Fiber/PMT pixel in near detector (avoids overlaps).
- Multi-pixel PMTs (Hamamatsu M16)

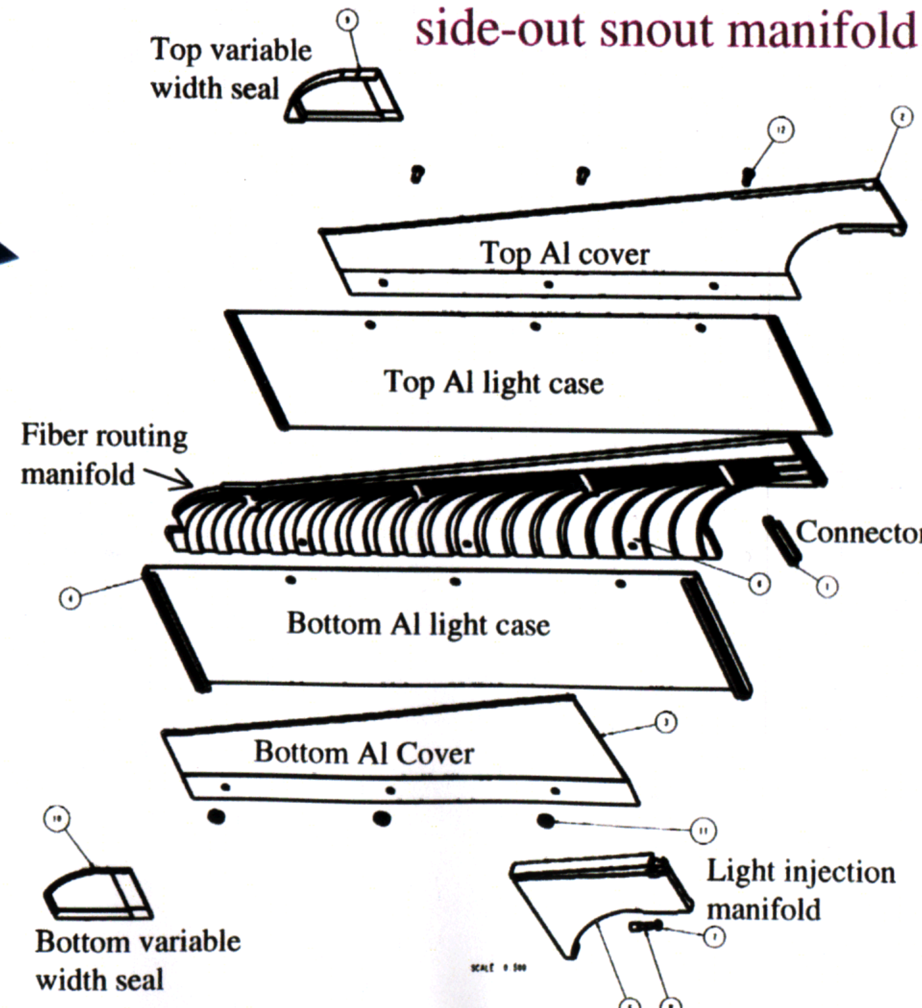


Objects not to scale

Module Components and Design

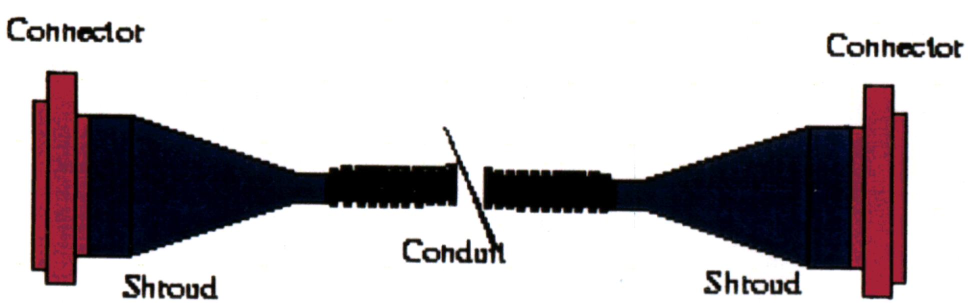
- The far detector module design is complete.
  - Final drawings exist for all components. Example
  - Light-tightness concerns addressed.
  - Final prototype components have been produced for use in "dress rehearsal" production at Argonne.
- Orders for module components are being developed.

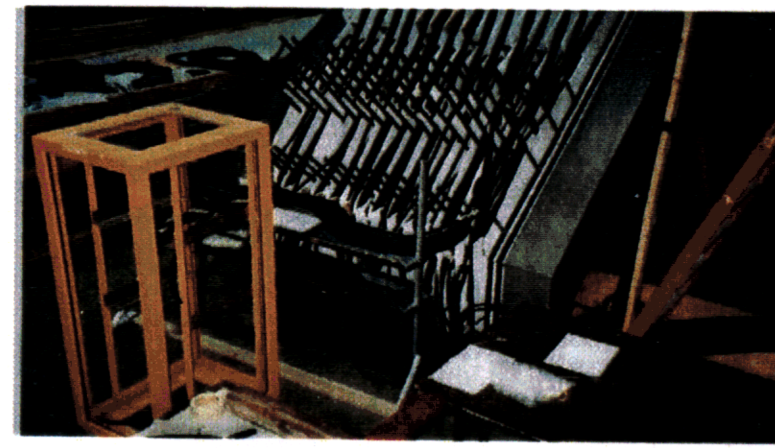
Assembly Drawing for side-out snout manifold

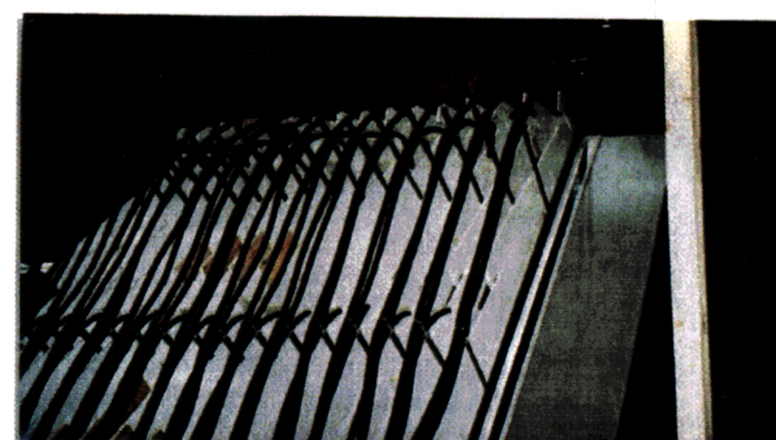


Clear Fiber

- We have changed the cable design:
  - « Adopt design used by D0.
    - * Already proven design!
    - * Fire safety issues already satisfied!
  - « Better light seal (problem found in 4PP)
  - « More robust.
  - « Lower cost!





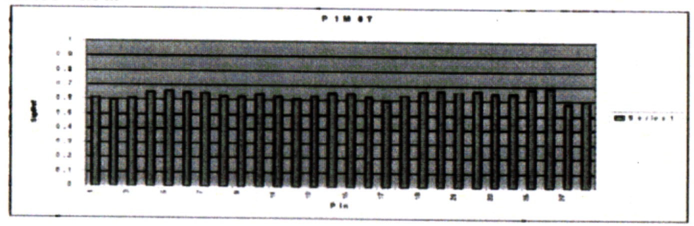


- Cable mockup in Muon Lab is being used to better define cable runs.

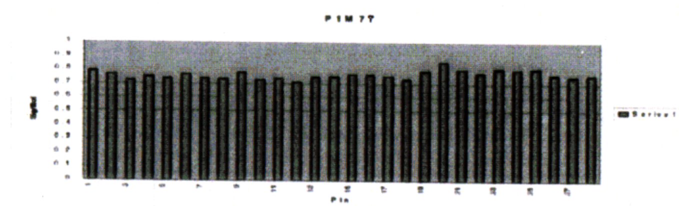
Transmittance of Clear Fiber

Clear Fiber Cable Transmittance – 4PPT

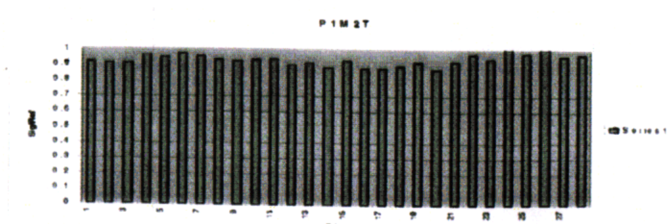
P1M8T – 6.1 m



P1M7T – 4.3 m



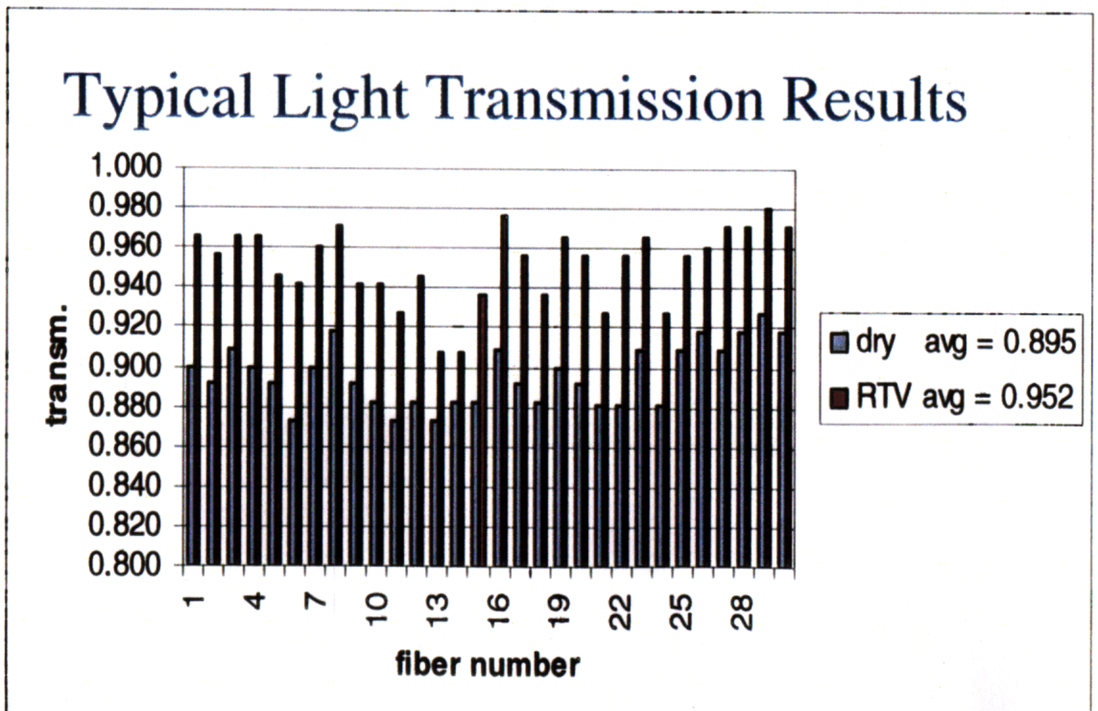
P1M2T – 1.9 m



Connector transmittance not included
Measured cable attenuation length = 11.3 m
Typical transmittance variance with cable ~ 4.5%

Light Throughput of Fiber Connectors

- 30-wide optical connectors have been successfully injection molded (important for low cost).
- Ready to proceed with full production.



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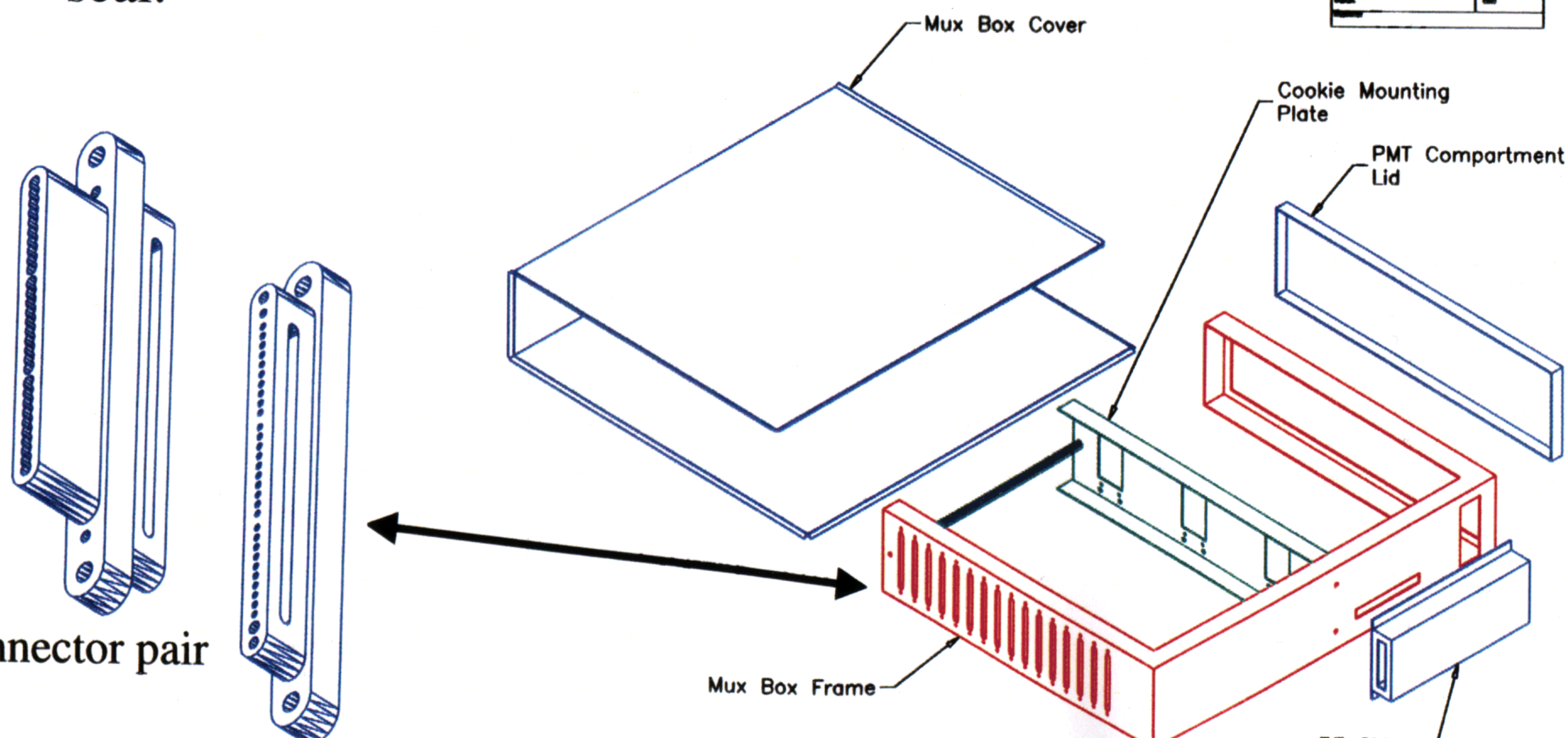
MUX Boxes

- Far detector MUX box design is complete.
- Final prototype being assembled and tested for light seal.

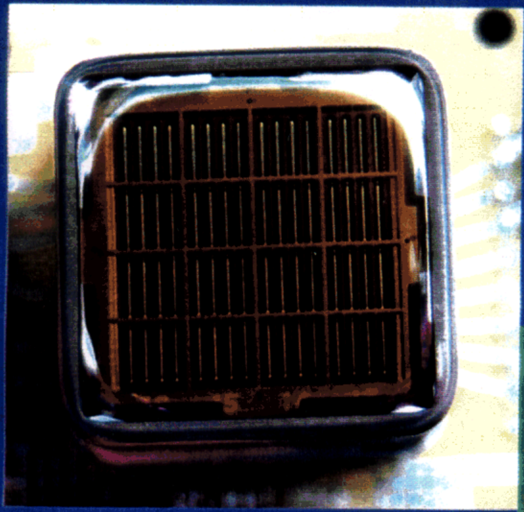


Connector pair

M16 and M64 for MINOS

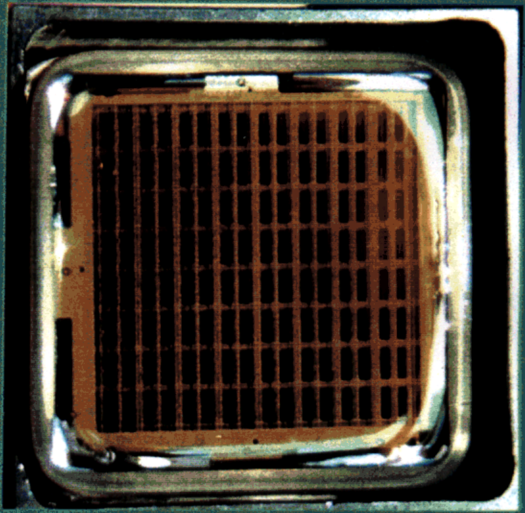
FAR Detector

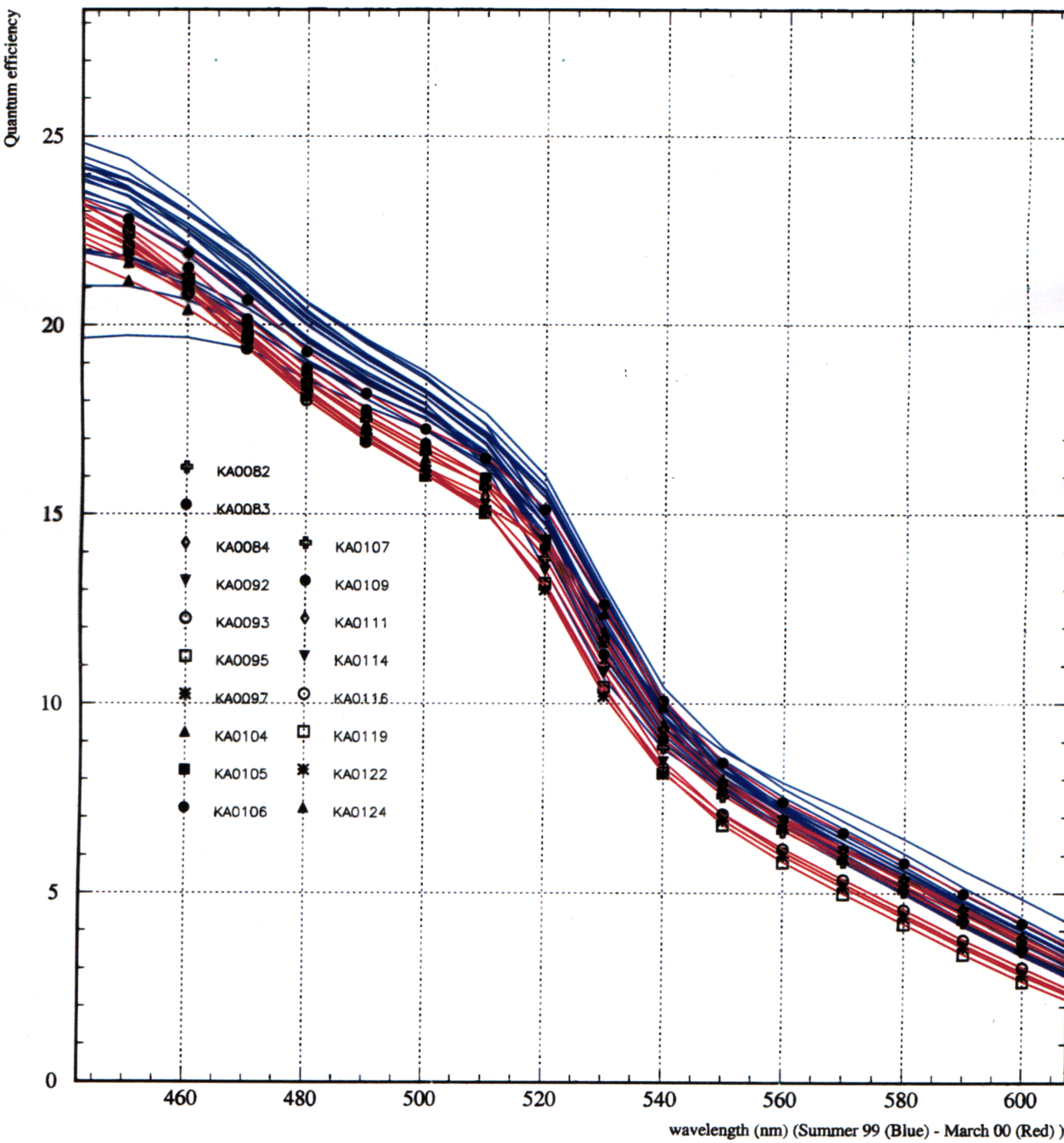
- Hamamatsu's R-5900-M16



NEAR Detector

- Hamamatsu's R-5900-M64





Quantum efficiency
25
20
15
10
5
0
460
480
500
520
540
560
580
600
wavelength (nm) (Summer 99 (Blue) - March 00 (Red))
KA0082
KA0083
KA0084
KA0092
KA0093
KA0095
KA0097
KA0104
KA0105
KA0106
KA0107
KA0109
KA0111
KA0114
KA0116
KA0119
KA0122
KA0124

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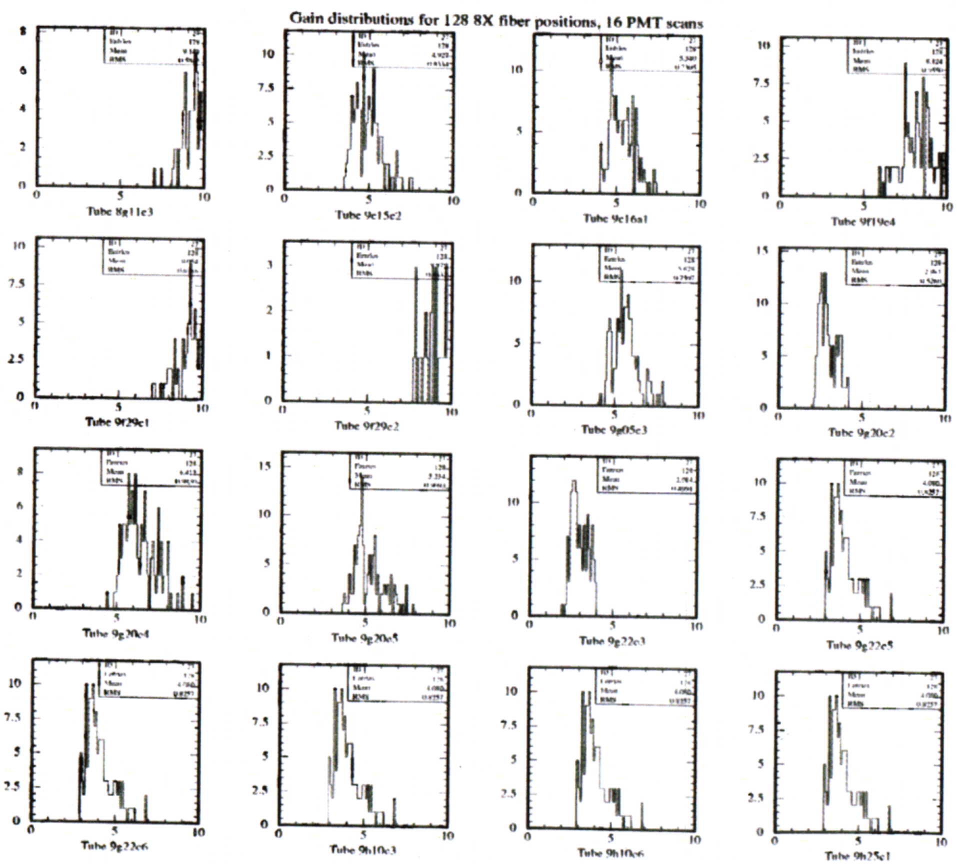
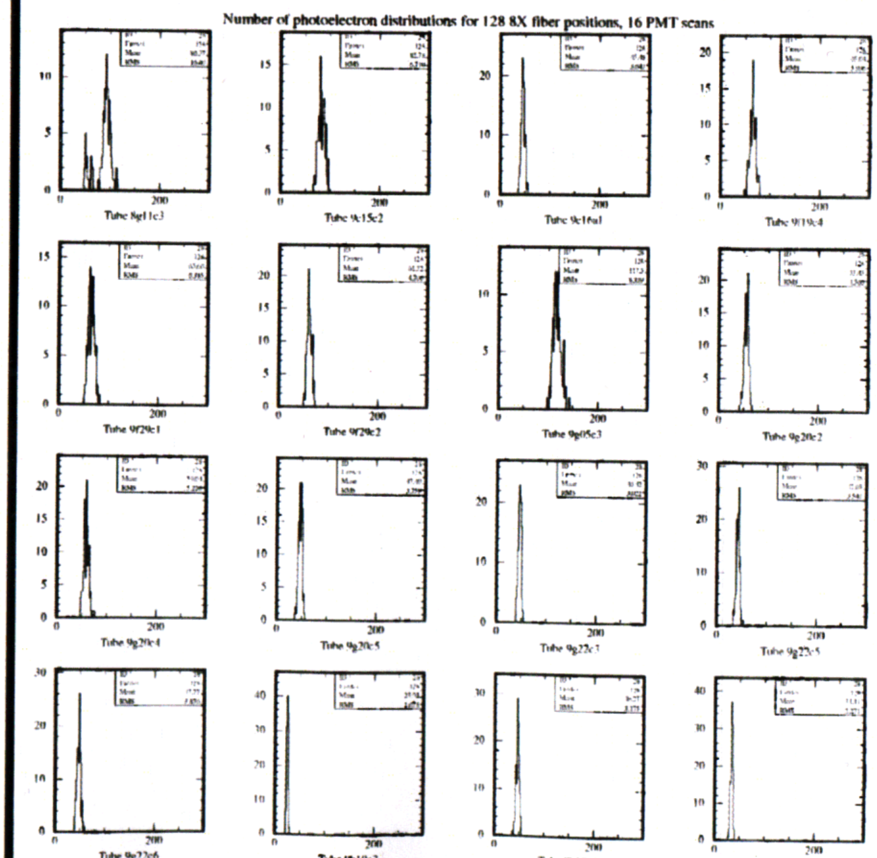
Summary of M16 Response Measurements

Gain Distributions for 16 Tubes



$\sigma_{gain}/gain \sim 0.15$

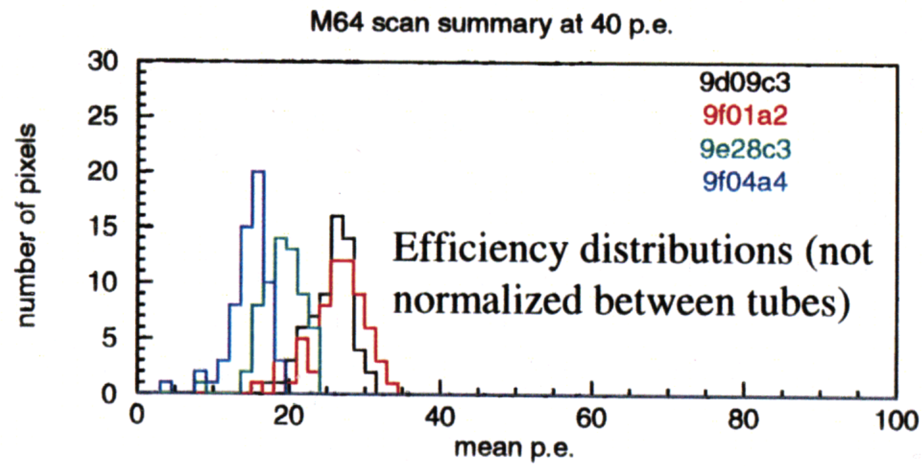
Relative efficiencies for 16 tubes

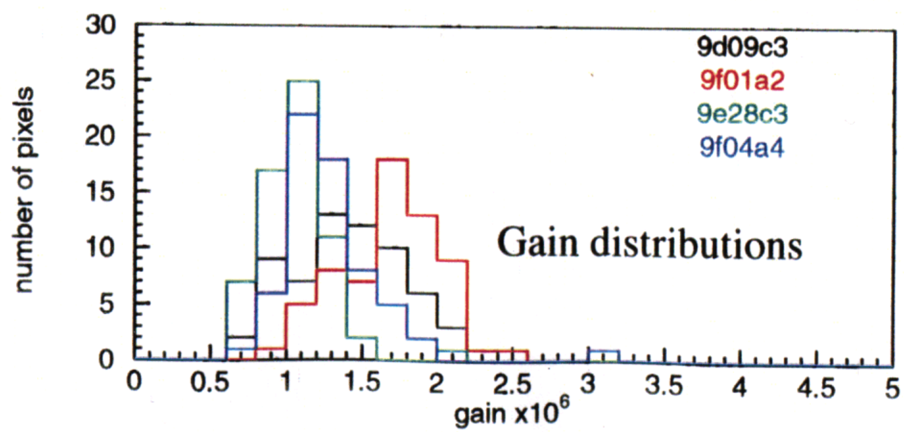


$\sigma_{eff.}/eff. \sim 0.07$

M64 Measurements

- M64 response looks very similar to M16 (not a surprise).
- M64 QE may be slightly lower than new M16s.
- M64s are more efficient for non-multiplexed system.





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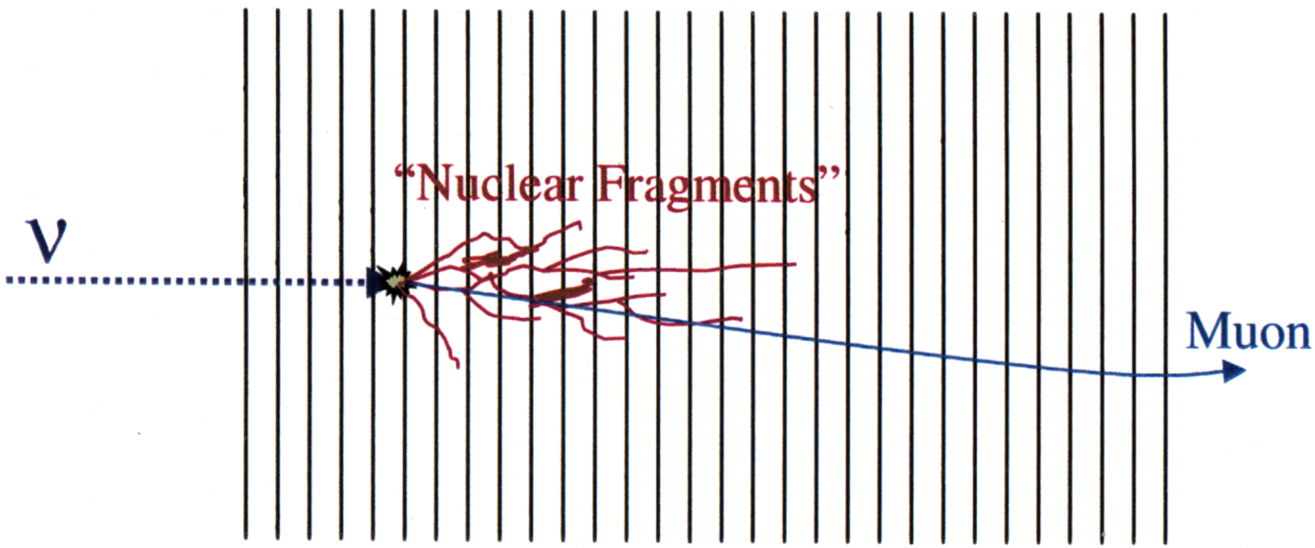
MINOS Physics Goals

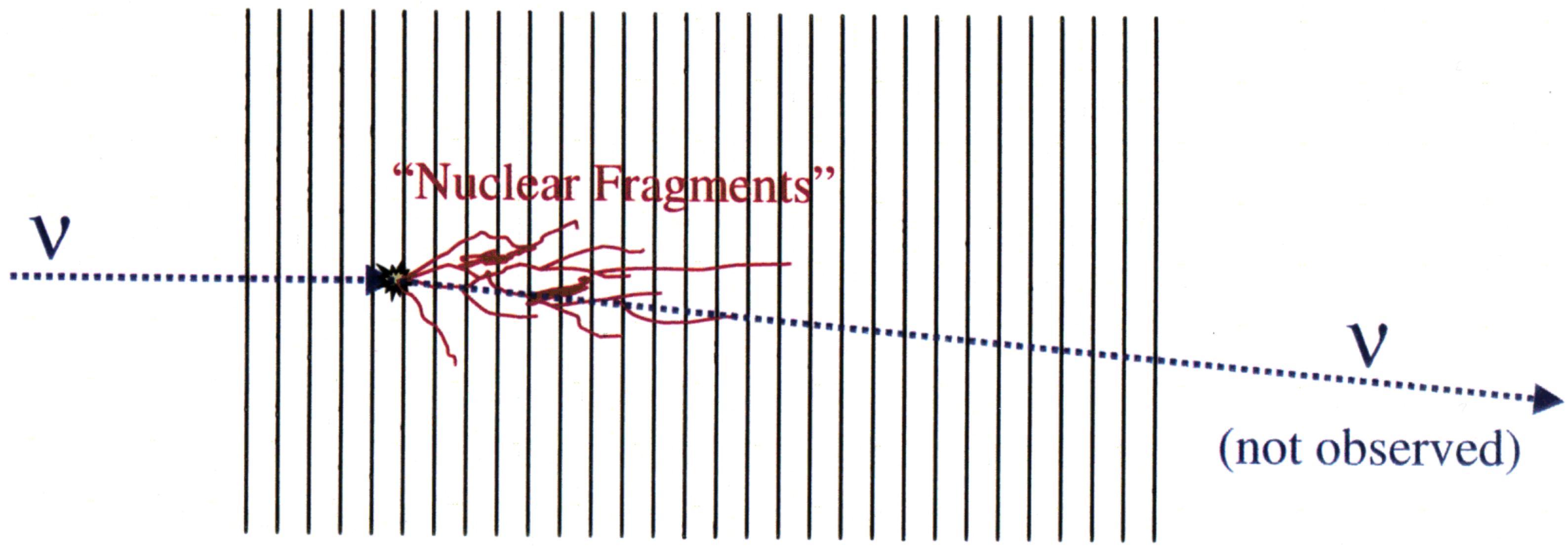
- Demonstrate Oscillation Behavior
  - « Precise measurement of CC energy distribution between near and far detector (1-2% systematic uncertainty).
  - « "Standard" or non-standard oscillations?
- Precise Measurement of Oscillation Parameters
- Precise Determination of Flavor Participation
  - « Number of CC ν_μ events far/near ~1-2%: Probability for $\nu_\mu - \nu_x$ oscillation.
  - « Number of CC ν_e events far/near: probability for $\nu_\mu - \nu_e$ oscillation down to about 2%.
  - « Number of NC events far/near: probability for $\nu_\mu - \nu_{sterile}$ oscillation down to about 4%.

Muon Neutrino CC Events in MINOS



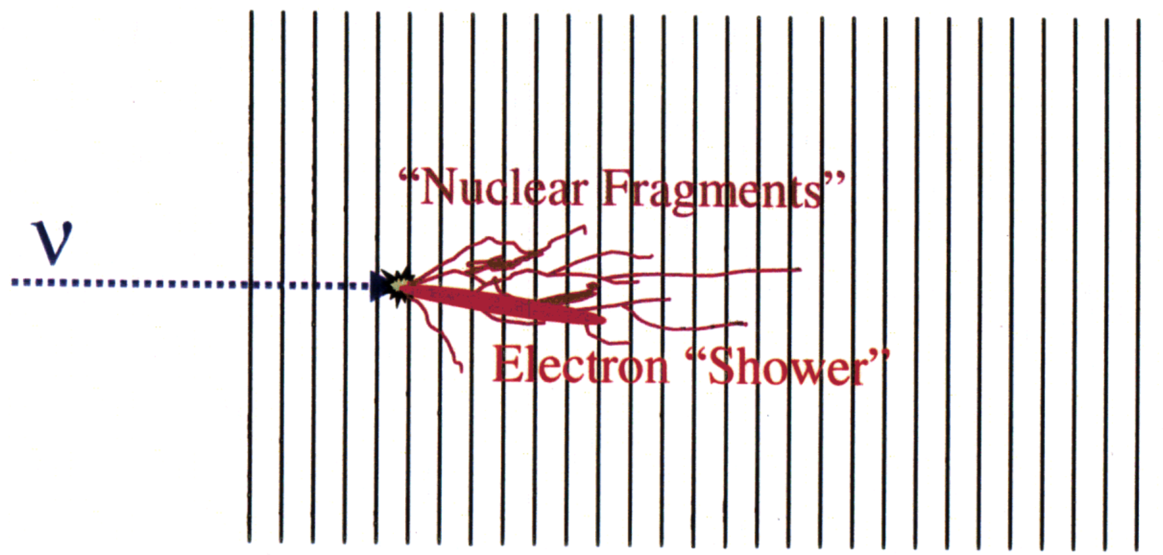
- A muon with enough energy to penetrate beyond the hadronic shower region is produced in most of these events, producing a "tail".
- The muon will curve as it moves through the magnetic field. Momentum is measured by range and curvature at low energies (typically below about 5-8 GeV) and curvature at high energy.
- In addition to the muon, "nuclear fragments" will be observed.

Neutral Current Events in MINOS



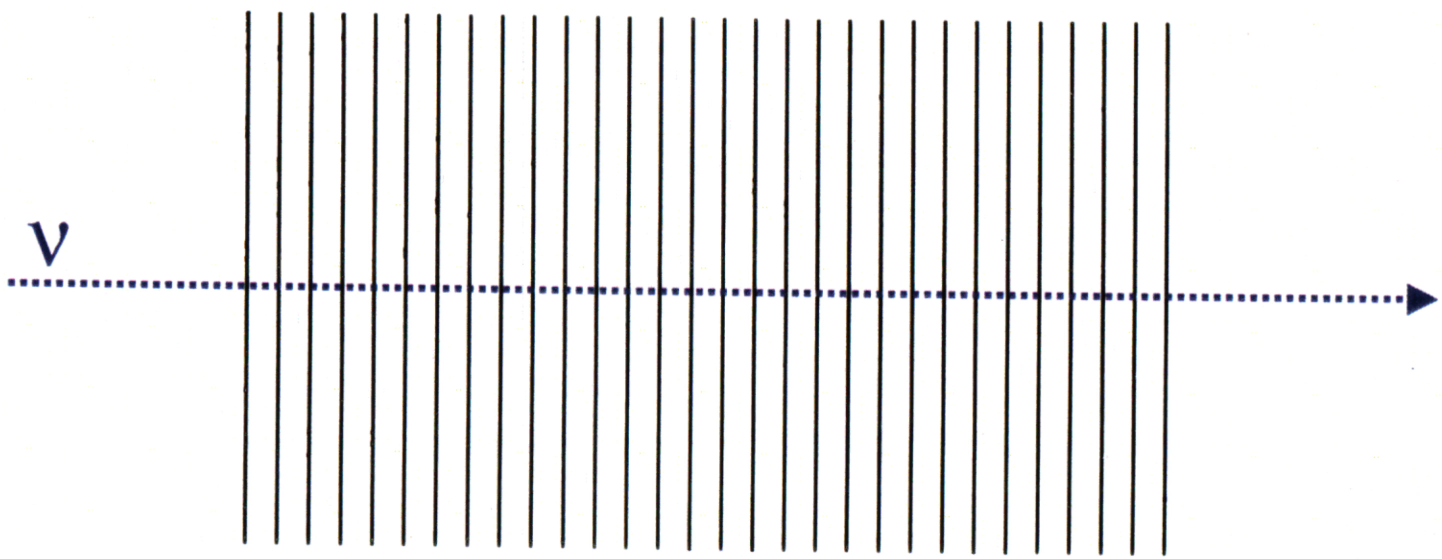
- Just nuclear fragments… no muon.
- EM showers from π^0s typically have lower energy than.

Electron Neutrino Events in MINOS



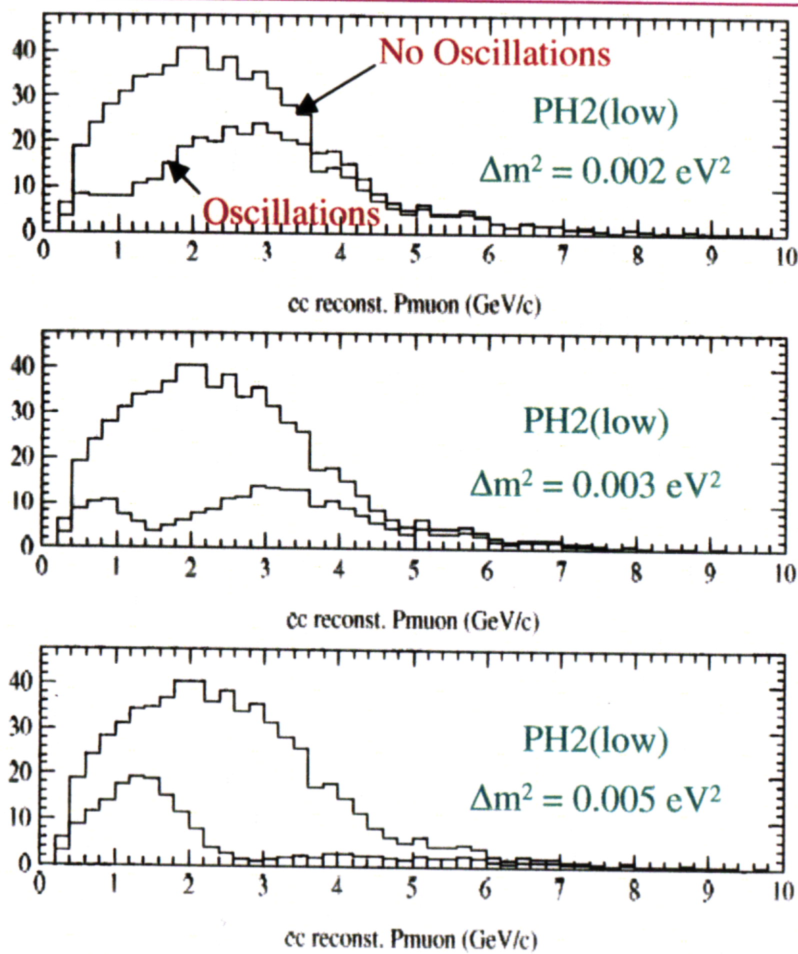
- Electron Neutrino Events:
  - An electron is produced in most of these events.
  - The electron produces a very intense “shower” of particles which produce a large amount of light in a narrow “cigar-shaped” region.
  - The shower extends a much shorter length than muons.
  - Nuclear fragments can also be produced.

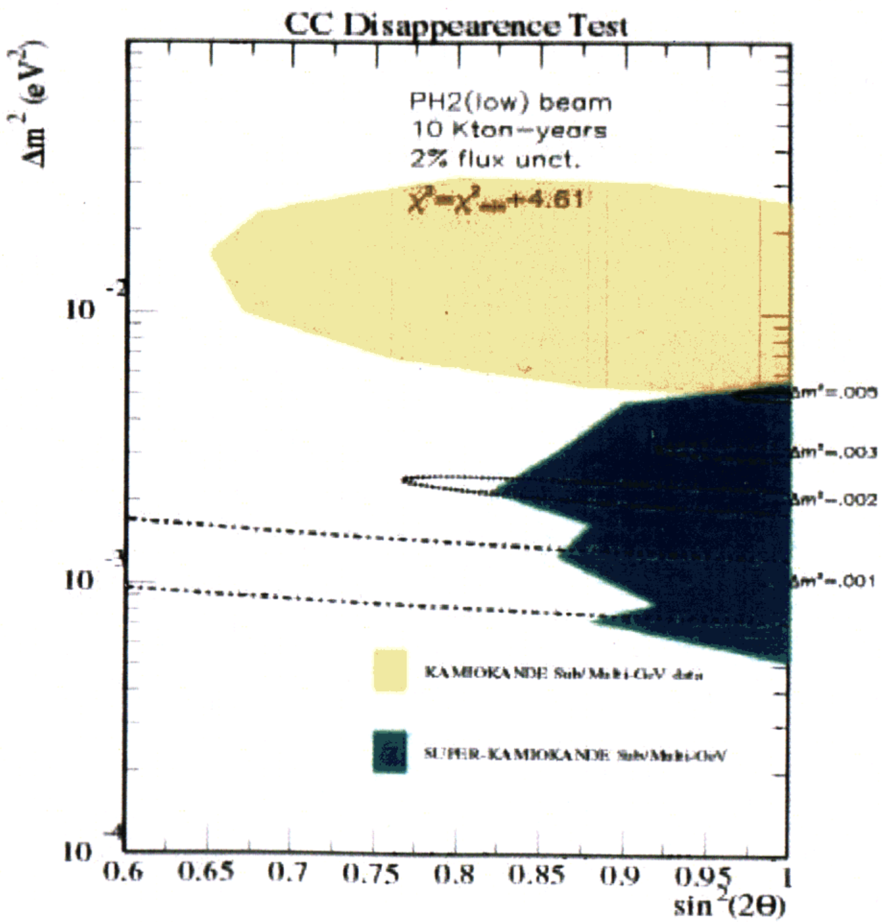
"Sterile" Neutrino Events in MINOS



- "Sterile" Neutrino Events:
  - "Sterile" neutrinos never stop in the detector! We can only "see" them by predicting how many of the other neutrino types we should have seen.
  - Its like waiting for a bus that never shows up. The schedule says it should have been there but something must have happened to it!

Measurement of Oscillations in MINOS

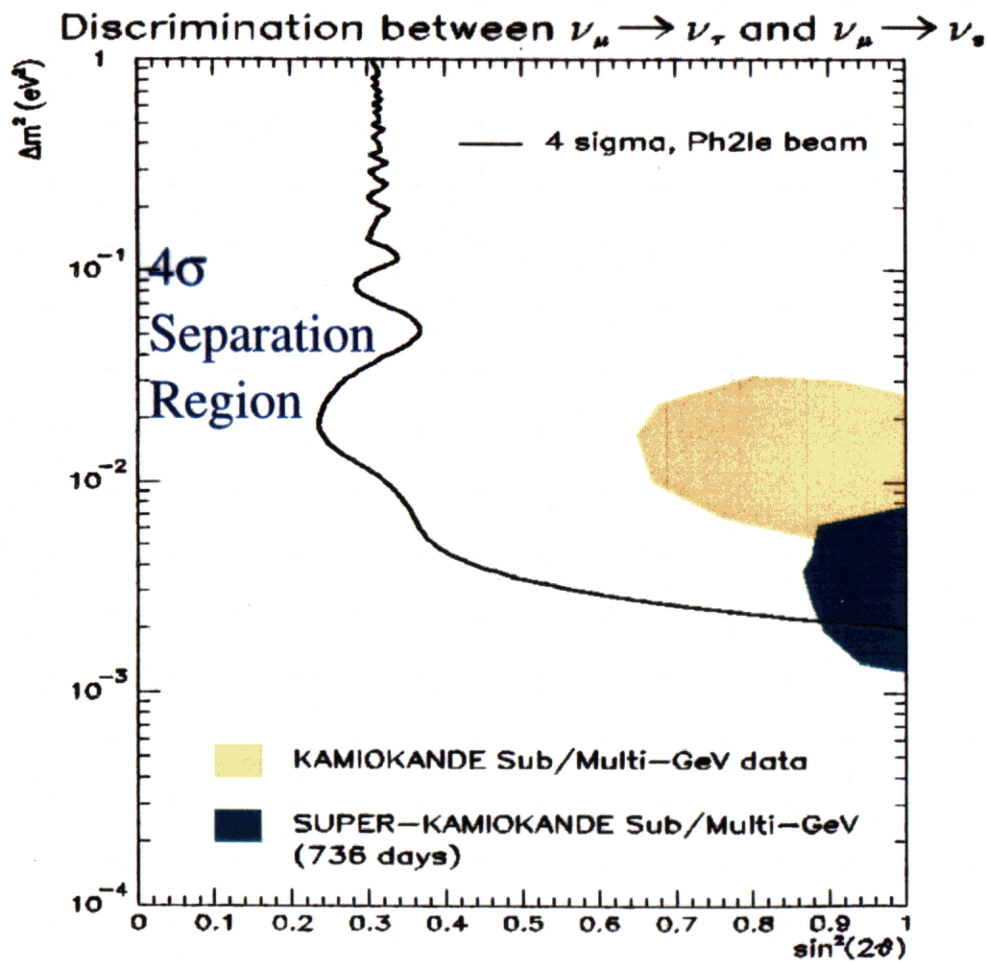




Flavor participation (including NC) measured to a few percent.

MINOS Oscillation Mode Sensitivity

(Discriminate $\nu_\mu \to \nu_\tau$ vs. $\nu_\mu \to \nu_{sterile}$)



Use CC/NC Ratio to distinguish between oscillations to ν_τ or $\nu_{sterile}$

- For $\nu_\mu \to \nu_\tau$, CC production of τ's will look like NC ~80% of the time

  CC/NC down

- For $\nu_\mu \to$ sterile , both CC and NC will be suppressed.

  CC/NC stays ~ constant

MINOS Low Δm^2 Sensitivity